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Vulnerability of Public Buildings in Sabah Subjected to Earthquake by Finite Element Modelling

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Abstract

This paper presents the vulnerability of public buildings in Sabah which are subjected to earthquakes from Sumatra and the Philippines. Tremors in Peninsular Malaysia and East Malaysia due to Sumatra and Philippine earthquakes have been reported several times. Engineers are concerned of the seismic vulnerability of public buildings due to lack of earthquake consideration in Malaysia's building design procedure. 8 (eight) reinforced concrete buildings which are mostly categorized as moment resisting frames has been selected for vulnerability study. A case study has been conducted on low rise, medium rise, and high rise buildings. The buildings are analyzed using Finite Element Modeling (FEM) under different types of analyses including Time History Analysis (THA) considering low to medium earthquake intensities. Different intensities of earthquake load, 0.05g, 0.10g, 0.15g and 0.20g are applied to the structures to know the maximum allowable earthquake load intensities for the buildings. In the non-linear analysis of modal frames, it indicates that most of the buildings are categorised in the moderate damage level where there is no structural damage but some non-structural damage are expected. The performances of the structure are shown by the yield point at beam-column connections where the internal forces at beam elements exceed the design capacity of the beams. The Labuan Airport building was performed the early yielding point at 3.85 sec for column element at intensity 0.05g. The study indicates that the plastic hinge initially formed on the column at the lower storey level for both low and high rise building frames.

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Keywords: Building vulnerability; seismic demand, dynamic analysi; non-linear analysis :

1. Introduction

In recent years, Malaysia is more aware of the seismic effect on its structures because of tremors have been repeatedly felt over the centuries from earthquake events around Malaysia. Most bridges in Malaysia

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do not take earthquake loadings into structural design consideration. A case study conducted by Tan [11] on the behaviour of high-rise buildings under seismic effect for Petronas Twin Tower (KLCC) used the Finite Element Analysis. The studies on performance of high rise buildings in Malaysia with various intensities of earthquakes using the Finite Element Modeling have been conducted by [7] and [12]. Therefore, the assessment due to seismic is very important in order to recognize the performance of the buildings. A seismic risk analysis addressed to earthquake emergency management and protection strategies planning, requires vulnerability and damage evaluation performed at territorial scale [2]. IDARC-2D dynamic non-linear analysis software is used to analyse the structures with different intensities load to know the maximum allowable earthquake load intensity for the buildings.

Suradi [9] also adopted the performance based seismic engineering in her study. The intent of earthquake resistance design therefore has become one of attempting to limit the damage experience by a building to levels, which are considered acceptable by structural engineers. Historically, damage that would not result in loss of life was deemed acceptable for most structures [3]. Performance-based seismic engineering (PBSE) is defined as the procedure of design and construction of structures that will resist earthquakes in a predictable manner [3]. It is to make owners and designers capable of selecting alternative performance goals or objective for the design of different structures. Severe earthquakes are relatively frequent events, which may or may not ever occur within the life of a building.

IDARC2D involves the non linear analysis by using IDARC-2D. Barron[4] chose the IDARC 2D two-dimensional inelastic finite element analysis program for RC structure [5] to perform the nonlinear dynamic analysis and found that a flexible diaphragm model produces more frame displacement and interstorey drift than the rigid diaphragm model.

Suradi [9] studied the comparison on the effect of earthquake and wind loads on the performance of reinforced concrete buildings by using IDARC2D to analyze the seven buildings due to dynamic non-linear analysis. Various earthquake ground accelerations (0.05g, 0.10g, 0.15g, and 0.20g) were used in earthquake Static Equivalent, Response Spectrum and Time History Analysis. The ground motions were scaled to 5% damped spectral acceleration at the fundamental frequency of the structure. Under the earthquake linear static analysis, the performances of the medium and high-rise reinforced concrete buildings were generally deemed satisfactory under 0.20g intensity earthquake level.

The performance level is a qualitative statement of damage. For it to be quantitatively defined, the performance level must be converted to the limiting values in the structural response parameter, which reflect the expected damage state. The ATC-13 damage level [10] was adopted by Alel [6] in defining the damage state level by referring to Table 1.

Table 1: ATC-13 Damage levels [10]

SEAOC Earthquake Level	SEAOC Damage	ATC-13 Damage Factors (State)
Minor	Without any damage	D.F.* = 0 (None) D.F. < 0.01 (Slight)
Moderate	No structural damage, some non-structural damage	0.01 < D.F. <=0.10 (Light) 0.01 < D.F. <=0.30 (Moderate)
Major	No collapse, some structural damage, non-structural damage considerable	0.30 < D.F. <= 0.60 (Heavy) 0.60 < D.F. < 1.0 (Major)
Collapse	Collapse	D.F. = 1.0 (Destroyed)

D.F.* = Damage Factor = Damage Index

Table 2: List of buildings analysed

No.	Building Name	No. of Story	Height (m)
1.	Bangunan Telekom Kota Kinabalu (BTKK)	5	27.50
2.	Sekolah Kebangsaan Bombalai Tawau (SKBT)	4	13.80
3.	Wisma Dang Bandung Kota Kinabalu (WDBKK)	12	39.90
4.	Wisma Pesekutuan Sandakan (WPS)	8	34.86
5.	Airport labuan (AL)	3	20.00
6.	Wisma Persekutuan Tawau (WPT)	8	34.86
7.	Perumahan Kastan Kudat (PKK)	5	17.00
8.	Hospital Duchess Sandakan (HDS)	4	21.60

This study highlights the seismic performance of public buildings owned by the government. Random site locations were chosen in Sabah. In order to analyze the seismic performance of the buildings, a single main frame was chosen from each building for the modeling in the finite element analysis. The IDARC software was used to analyze the structures through non-linear dynamic analysis. There are eight (8) districts around Sabah including Kota Kinabalu, Tawau, Sandakan, Labuan and Kudat. Table 2 shows the list of buildings analysed in this study.

2. Dynamic Non-Linear Analysis

The scopes of the study are to study the performance of buildings of less than 20 stories by using Finite Element Modeling for dynamic non-linear analysis (IDARC 2D) and to use a variation of low earthquake intensities (0.05g, 0.10g, 0.15g, and 0.2g) in the analysis with the ground motion scale of 5% damped spectral acceleration. The El-Centro time history data is shown in Figure 1. A single main frame was chosen from each building for the modeling in the finite element analysis.

2.1 *Modeling Concept*

Figure 2 shows the plan view of the Labuan Airport. The structural framing system is highly visible and the building is readily classified as concrete moment resisting frame and the analysed frame 5/A-D can be seen in Figure 2. The building height is equal to 18.00 m which is categorised as a medium-rise building (4 stories). The materials of properties are 2500N/mm^2 (Ec), 460N/mm^2 (fy), 27.6N/mm^2 (fc) and 25mm for cover (c). Loadings applied in the analysis were determined according to British Standard [1].

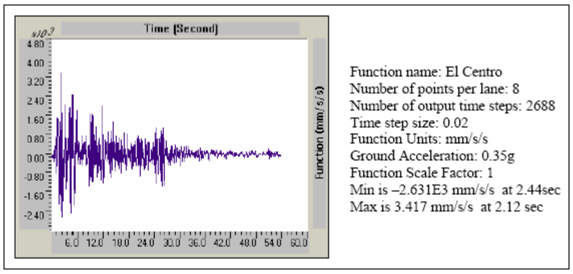

Figure 1: Time History Record of Imperial Valley Earthquake (May 18,1940 – El Centro)

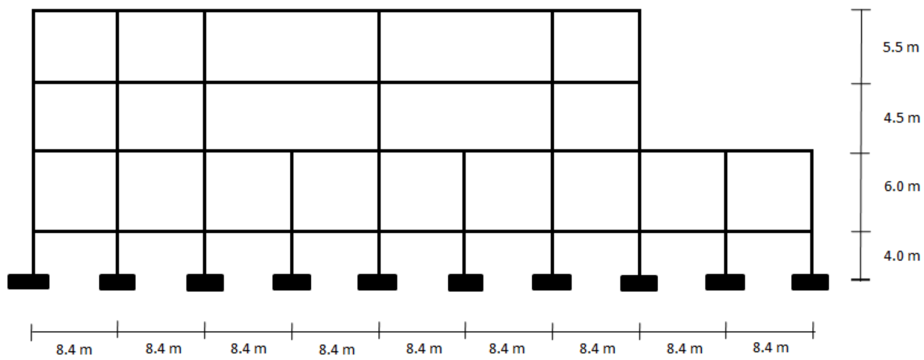

Figure 2: Moment Resistance Frame of Airport Labuan (AL)

3. Results and Discussion

3.1 *Damage Pattern Due To Plastic Hinge*

For moment resisting frame type of buildings, the plastic hinges due to structural local failures normally occur either at beam or column connection. Table 3 shows the summary of the first development of plastic hinges on the local structural element for each building in Sabah. From the results, most of the buildings that developed plastic hinge due to the lowest earthquake intensity of 0.05g. The plastic hinge initially formed on the beam at lower storey level of all low-rise, and medium-rise building while the plastic hinge initially formed on the column at high-rise of building frames. The Airport Labuan building frames were the earliest to experience first yielding on column element at 3.85sec with the intensity of 0.05g.

Figure 3 shows the damage state location and plastic hinge formation of Labuan Airport. To represent the sequences of damage state of frames under El-Centro earthquake, four intensities of ground acceleration of 0.05g, 0.10g, 0.15g and 0.2g are shown in Figures 3 (a), (b), (c) and (d). From the resultant dynamic nonlinear analysis under earthquake loads, the modal frame experienced cracking and yielding at the beam and column elements. The 'x' symbol denotes the crack formation for concrete and the 'o' symbol denotes the severe yield of plastic hinge formed.

Table 3: Summarisation of first yielding points for all buildings

Building Name	No. of Story	Location of Plastic Hinge	Flo or level	Intensities (g)	Time of First Yielding (sec)
Bangunan Telekom Kota Kinabalu (BTKK)	5	-	-	-	-
Sekolah Kebangsaan Bombalai Tawau (SKBT)	4	Beam	3	0.05	7.30
Wisma Dang Bandung Kota Kinabalu (WDBKK)	12	-	-	-	-
Wisma Pesekutuan Sandakan (WPS)	8	Column	1	0.05	5.03
Airport labuan (AL)	3	Column	1	0.05	3.85
Wisma Persekutuan Tawau (WPT)	8	Column	1	0.05	5.03
Perumahan Kastan Kudat (PKK)	5	Beam	2	0.10	4.61

Hospital Duchess Sandakan (HDS)	4	Beam	2	0.15	7.64

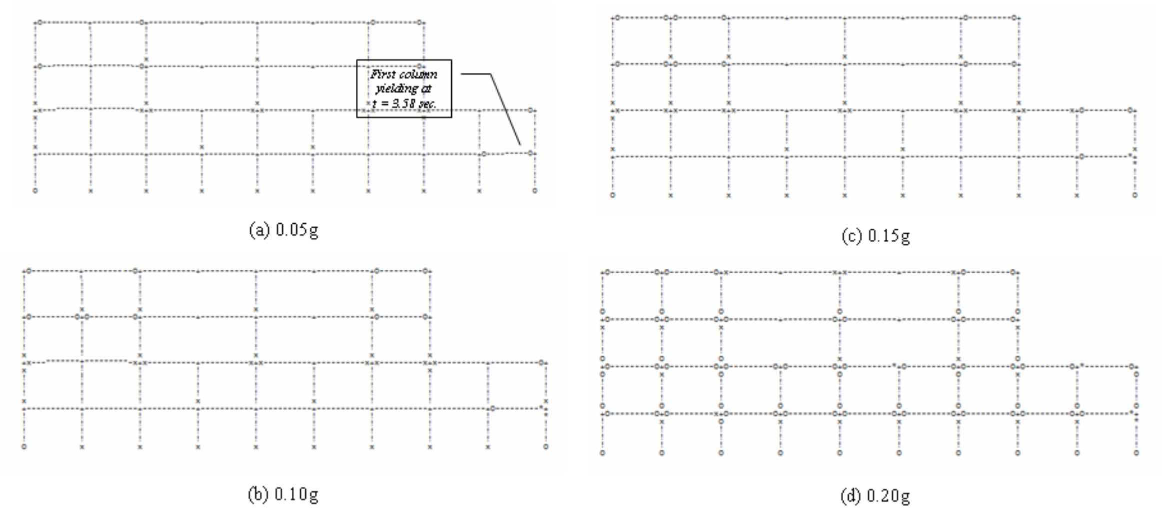

Figure 3 : Damage state frame under 0.05g, 0.10g, 0.15g, and 0.20g earthquake intensity for Airport Labuan building.

3.2 *Damage Analysis*

In this study, the damage analysis of buildings was carried out by using the original version of the program developed by Park [8] to provide a measure of the accumulated damage sustained by the components of the structure, by each story level, and the entire building. This damage index included the ratio of the maximum to ultimate deformations. Table 5 shows in detail the summary of overall damage index of each building in Sabah under various intensities; 0.05g up to 0.20g, The overall damage index for the building can be referred to the SEAOC Damage Level in Table 1.

The result shown in Table 4, only six (6) modal frames buildings in Sabah were able to resist up to 0.2.0 g of earthquake intensity. Sekolah Kebangsaaan Bombalai building in Tawau was affected by earthquake and collapsed when 0.20g intensity is applied to the building. This same goes to Hospital Duchess Sandakan (HDS). Bangunan Telekom Kota Kinabalu has no damage at 0.05g. While other buildings started experience damage at 0.05g with moderate level. It can be seen that most of the buildings were categorised in the moderate damage level where there is no structural damage but only obtained some non-structural damage of up to 0.15g intensity.

Table 4: Summarisation of first yielding point for all buildings

No.	**Building name**	**Overall Structural Damage Index**			
		0.05 g	**0.10 g**	**0.15 g**	**0.20 g**
1.	Bangunan Telekom Kota Kinabalu (BTKK)	0.000	0.032	0.046	0.060
2.	Sekolah Kebangsaan Bombalai Tawau (SKBT)	0.032	0.072	0.314	1.000
3.	Wisma Dang Bandung Kota Kinabalu (WDBKK)	0.024	0.032	0.046	0.082
4.	Wisma Pesekutuan Sandakan (WPS)	0.020	0.038	0.048	0.069
5.	Airport labuan (AL)	0.034	0.042	0.056	0.059
6.	Wisma Persekutuan Tawau (WPT)	0.020	0.038	0.048	0.069
7.	Perumahan Kastan Kudat (PKK)	0.019	0.028	0.060	0.111
8.	Hospital Duchess Sandakan (HDS)	0.023	0.027	0.029	1.000

4. Conclusion

It can be concluded that all buildings have different performances in terms of damage level when various intensities are applied to the buildings.

Most of the buildings analysed subjected to the El-Centro earthquake ground motion developed plastic hinge due to the lowest earthquake intensity of 0.05g and have damage indexes in range of 0.0 to 0.034. The damage analysis of concrete moment resistance frame building is discussed on the resultant of dynamic nonlinear analysis under various intensities; 0.05g, 0.10g, 0.15g, and 0.2g. Eight (8) concrete moment resistance frame buildings were analysed in this study. The result indicates that Eight (8) modal frame buildings in Sabah can resist up to 0.15g. It can be seen that all buildings were categorised in the moderate damage level where there is no structural damage but only obtained some non-structural damage.

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